GB

EXPLANATIONS

I) General-Section 2 (Data table)

1. "Type" column

All types are listed in alphabetical order. Outdated or insignificant types are set in small print. Type families are grouped together optically, i.e. not separated by a slash. In this case, the complete data is given only for the main type in the first line. For all other types, only the data differing from that of the main type is indicated together with the test conditions (e.g. BA159 " = BA157:").The same applies for subgroups (selections) of a type (type idendification with suffix letters, numbers or color codes) but without the indication "=...".
Types identified "AA..." to "BZ..." mainly cover the socalled proelectron code which is explained in the following.

The first letter identifies the basic material:

A	Germanium or equivalent (band gap 0,6...1,0eV)
B	Silicon or equivalent(band gap 1,0...1,3eV)
C	Gallium-arsenide or equivalent (band gap >1,3eV)
D	Indium-antimonide or equivalent (band gap <0,6eV)
R	Opto-Element material (e.g. cadmium sulfide)

The second letter identifies type and function:

A	Diode	M	Hall generator (closed circ.)
B	Varactor	N	Opto-coupler
C	AF transistor	P	Opto-element (sensor)
D	AF power transistor*)	Q	Opto-element (emitter)
E	Tunnel diode	R	Thyristor
F	RF transistor	S	Switching transistor
G	Microwave diodes, etc.	T	Power thyristor*)
H	Magnetic field diode	U	Power switching transistor*)
K	Hall generator (open circ.)	X	Multiplier diode
L	RF power transistor*)	Y	Power diode*)
		Z	Z-Diode, etc.

*) RthG<15°C/W

These two letters are followed by a 3-digit serial number (100...999) for standard types. Professional types have two letters followed by a third letter and a 2-digit number (10...99).

2. "Manufacturer" column

Names of manufacturers are abbreviated to save space. The complete names are listed alphabetically at the end of Section1. We cannot assume responsibility for completeness and availability. When more than one manufacturer is named for any type, only the data is given relative to one manufacturer, since the data of any type differs slightly from one manufacturer to the other due to the differing test conditions.

3. "Mat." column

Ge = Germanium
Se = Selenium
Si = Silicon
GaAs = Gallium arsenide

4. "Fig./Pin-code" column

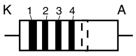
All case identifications are listed in Section 4 with an alphanumerical Fig. number. Similar case types are grouped together under a single letter and shown in roughly the same scale, thus facilitating comparison of size.
The small letters following the slash identify the pin code which is tabulated at the end of the drawings or on the yellow fold-out. *A/B/C/D/E/F represent the case dimensions fo drawings showing no dimensions.

5. "Application" (and remarks) column

The main application of each type is abbreviated to save space (see below). This column also contains any remarks pertinent to, for instance, coding, further data on special types and other useful instructions. * Color code is the type identification on small cases — instead of plain language — in the form of colored rings, strips or dots. The sequence always commences at the cathode end (usually with a broader ring). On subminiature types an alphanumerical type code is used (see also list at end of Section 4).

Abbreviations in the "Application" column

AFC	Automatic frequency control
AGC	Automatic gain control
AM	RF application (AM range)
Array	Arrangement of numerous elements in a sigle case
Backward	Backward diode (see Explanations II) 1.j)
band-S	RF band switching
bi-direktional	Bidirectional diode (see Explanations II) 1.d)
Br	Bridge rectifier
contr.av.	Controlled avalanche
Dem	Demodulator
Diskr	Discriminator
Dual	Dual diode
FED	Field effect diode
FM	RF application (FM range)
gep	matched types
Gl	Rectifier, general
Gunn-Di	Gunn diode (see Explanations II) 1.l)
HF	RF applications
h-ohm	for high impedance demodulator circuits
hi-rel	High reliability
Impatt-Di	Impatt diode (see Explanations II) 1.m)
Iso	insulated
kl	TV clamping diode
L	Power type
M	Mixer stages
Min	Miniature type, SMD
multipl	Frequency multiplier
NF	AF applications
n-ohm	for low impedance demodulator circuits
O	Oscillator stages
Opto	Opto-electronic components
PIN-Di	PIN diode (see Explanations II) 1.c)
ra	low noise
S	Switching stages
Schottky	Schottky diode (see Explanations II) 1.k)
SN, SMPS	Switch-mode power supplies
SS	Super-fast switching stages
Stabi	Stabilizer diode, forward operation (see Explanations II) 1.f)
stack	Rectifier stacks
TAZ	Suppressor diode (see Explanations II) 1.e)
tuning	RF tuning diode
Tunnel-Di	Tunnel diode (see Explanations II) 1.h)
TV	TV applications
Typ-Code	Type code (see also list at end of Section 4)
UHF	RF application (> 250MHz)
UJT	Unijunction type (see ECA volume "tht")
Uni	General purpose type
VHF	RF application (approx.100...250MHz)
Vid	Video stages
Z	Z-diode, reverse operation (see Explanations II) 1.d)
Z-Ref	Reference voltage diode (see Explansions II) 1.g)
→	see



Color code (JEDEC “1N...-types”)

Color abbreviations:			Ring1...4	Ring5
sw	=	black	0	—
br	=	brown	1	A
rt	=	red	2	B
or	=	orange	3	C
ge	=	yellow	4	D
gn	=	green	5	E
bl	=	blue	6	F
vi	=	purple	7	G
gr	=	gray	8	H
ws	=	white	9	J
go	=	gold	—	—
si	=	silver	—	—
rs	=	pink	—	—

Frequency band identification (UHF-/microwave diodes)

L band	1.12...1.7GHz
S band	2.6...3.95GHz
G band	3.95...5.85GHz
C band	4.9...7.05GHz
J band	5.85...8.2GHz
X band	8.2...12.4GHz
M band	10...15GHz
Ku band	12.4...18GHz
K band	18...26.5GHz
R band	26.5...40GHz
Q band	33...50GHz
Ka band	26.5...40GHz

II) Notes regarding Section 2 (diodes and similar components)

1. General

The diodes described in the following belong to the active semiconductor components on a silicon, germanium, selenium or similar substrate. Doping the substrate in its original highly pure, poorly conducting state produces P (positive) and N (negative) conducting crystal layers.

a) Diodes and rectifiers

The boundary between P and N conducting material is formed by a junction (barrier layer). The basic characteristic of a diode of this kind is shown in Fig. 2.

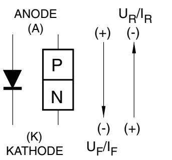


Fig. 1

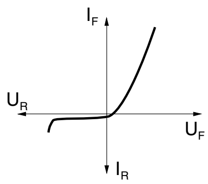


Fig. 2

When the voltage potential at the anode is positive as compared to the cathode (forward direction), the forward current (I_F) greatly increases with increasing forward voltage (U_F) whilst the forward resistance (R_S) is greatly reduced.
When the potentials are reversed (reverse direction), only a low reverse current (I_R) flows in the zone of permissible reverse voltage (U_R/U_{RM}). The reverse resistance is high. The junction capacitance (C_T) decreases with increasing reverse voltage (U_R). When the permissible reverse voltage is exceeded, the reverse current increases steeply (avalanche) which would quickly result in normal diodes being destroyed. Only controlled avalanche types permit this kind of operation within prescribed limits.
Due to their valve effect, diodes are particularly suitable for rectification of AC voltages, as RF demodulators, switches and the like.

b) Varactors (Varicaps)

The junction capacitance (C_T) in each P/N junction depends on the reverse voltage and thus specially developed types are used for tuning, AFC, RF band switching, modulators, controlled band width stages, etc. Figure 3 shows the symbol and simplified RF equivalent circuit diagram. The series resistance (r_S) changes with frequency and is reduced with increasing reverse voltage. LS is the series inductance.
Since the basic C_T/U_R characteristic (Fig. 4) is non-linear, distortion occurs at high RF signals. The RF signal amplitude should be small as compared to U_R. In addition, two matched diodes in push-pull circuit will practically compensate the non-linearity.

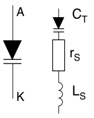


Fig. 3

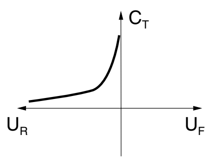


Fig. 4

Snap-off diodes (charge storage diodes, step recovery diodes)
are specially doped to permit extremely fast switching (Fig.16) or for use as UHF frequency multipliers up to microwave frequencies in a corresponding design and mode of operation.

c) PIN diodes

In PIN diodes an intrinsic layer of high impedance is located between the P and N zone. The diode resistancecan be changed by a few orders of ten by application of a variable DC voltage. For this reason, PIN diodes are suitable as low-loss, variable RF attenuating elements and as RF switches.

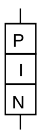


Fig. 5

d) Z-diodes (Zener diodes)

Silicon Z-diodes are operated in reverse, the reverse current hardly changing at first when the reverse voltage is applied. The reverse current (I_Z) increases steeply when the typical Z-voltage (U_Z) is attained as a result of avalanche breakdown (Z-breakdown). The applied voltage then changes only slightly as a function if I_Z (Fig. 7).
Z-diodes are thus excellently suitable as voltage stabilizers.

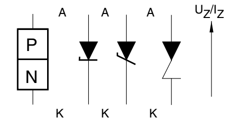


Fig. 6

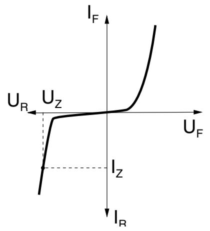


Fig. 7

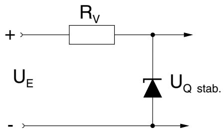


Fig. 8

The steeper the increasing current (I_Z), the smaller the dynamic resistance (r_Z) and the better the stabilizing properties of a Z-diode. Typical breakdown voltages of 2.4...200V can be attained. The temperature coefficient is almost zero for 5 - 6V types, positive at higher voltages and negative at lower voltages. The maximum permissible power dissipation must not exceed the product of I_Z x U_Z in operation.
Two Z-diodes in push-pull with a common cathode or anode (bidirectional/back to back) can be used for symmetrical voltage limiting.

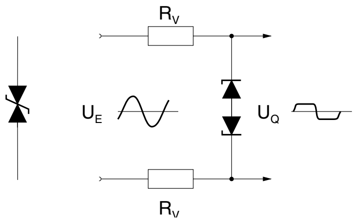


Fig. 9

e) TAZ-suppressor diodes (overvoltage limiting diodes)

TAZ diodes (**t**ransient **a**bsorbtion **z**ener) are Z-diodes capable of absorbing pulse power up to a number of kilowatts within a few picoseconds, and thus serve to protect circuits and devices from overvoltages and surges.

f) Stabi diodes (stabistors)

Since practically no Z-breakdown occurs at voltages below 2.4V, the lower curved part of the forward characteristic of diodesis used for voltage stabilization (Fig. 2).

Fig. 10

Stabi diodes comprise one or more diodes in series exhibiting a small range of U_F in forward operation over a wide I_F range. Usual types are $U_F = U_{stab}$ = 0.7V (1diode), 1.4V (2 diodes), 2.1V (3 diodes), 2.8V (4 diodes) and 3.5V (5 diodes). For higher voltages Z-diodes are used in reverse operation.

g) Reference Z-diodes

Reference diodes are provided for highly constant voltage stabilization, comprising a series arrangement of Z-diodes with positive temperature coefficient and stabi diodes with negative temperature coefficient, so that the temperature coefficients practically cancel each other out.

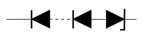


Fig. 11

h) Tunnel diodes (Esaki diodes)

Tunnel diodes consist of extremely high doped germanium. These diodes have no reverse property ($I_{FM} = I_{RM}$).
The characteristic (Fig. 12) exhibits an initial steep rise followed by a falling sector. When the voltage is further increased, the characteristic assumes the profile of a normal diode.
Due to the undamping effect when operated over the sector of the falling characteristic (area of negative resistance), tunnel diodes are excellently suited for active oscillator circuits up to the UHF range, and as fast switches.

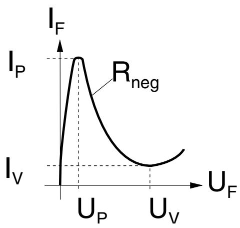


Fig. 12

j) Backward diodes

Like tunnel diodes, germanium backward diodes also exhibit an area of negative resistance in their characteristic which is, however, only weakly emphasized.

Backward diodes are suitable as demodulators and mixers in the microwave range. The steep increase in current over the forward range permits rectification of very small RF signals.

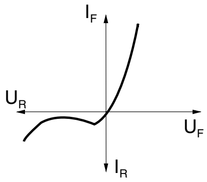


Fig. 13

k) Schottky diodes (Schottky barrier diodes, hot carrier diodes)

Schottky diodes usually exist of an N doped semiconductor layer which is connected to a metal. Since only majority carriers are available, the storage time is extremely low. These components are thus suitable as very fast switches and, due to the low noise property, also as mixer diodes in the microwave range.

Fig. 14

l) Gunn diodes (Gunn elements)

Gunn diodes have no P/N junction and are mainly fabricated in Gallium-arsenide (GaAs).When a voltage is applied to a Gunn diode, the space charge zones shift in keeping with a typical resonant frequency depending on the length of the active range in the semiconductor crystal, at which the diode exhibits a negative dynamic resistance.

By means of Gunn diodes, wideband oscillator circuits can be created in the microwave range (e.g. compact radar transmitter systems) directly from the DC energy. Simple tuning to the harmonic and subharmonic is also possible by means of external resonant circuits.

m) Impatt diodes (avalanche diodes, read diodes)

Unlike the Gunn diodes, impatt diodes feature P/N junctions.

Also utilized is the velocity of space charges for generating microwaves.

2. Data

All data given in the table has been carefully researched, tested, evaluated and presented in a clear arrangement. For some types, complete data was not available due to detailed documentation not, or no longer, being available.

a) Absolute maximum ratings

The stated absolute maximum permissible values must not be exceeded under any conditions, not even transiently. Unless stated otherwise, this data applies for 25°C.

- $\mathbf{U_R}$ **Reverse voltage** — Maximum permissible reverse DC voltage.
- $\mathbf{U_{RM}}$ **Maximum repetitive peak reverse voltage** — Maximum permissible peak value of the reverse voltage.
- $\mathbf{U_{eff}}$ **RMS input voltage** — Root-mean-square value of maximum input AC voltage.
- $\mathbf{I_F}$ **Forward current** — Maximum permissible forward DC current for a given temperature.
- $\mathbf{I_{AV}}$ **Forward current (= I_O = rectified current for small diodes)** — Maximum permissible arithmetic mean (whole cycle average) for a given temperature.
- $\mathbf{I_{eff}}$ **RMS forward current** — Root-mean-square value of maximum permissible forward current for resistive load at a given temperature.
- $\mathbf{I_Z}$ **Zener breakdown current** — Maximum permissible DC current for Z-diodes at breakdown (= P_{tot}/U_Z) at a given temperature.
- $\mathbf{I_{FM}}$ **Maximum peak forward current** — Maximum permissible peak value of forward current at a given temperature.
- $\mathbf{I_{FRM}}$ **Maximum repetitive peak forward current** — Maximum permissible repetitive peak forward current at agiven temperature.
- $\mathbf{I_{FSM}}$ **Non-repetitive peak forward curren**t — Maximum permissible surge current (usually for ½ cycle = 10ms, $T_j = T_{jmax}$), usually max.1μs for small diodes.
- $\mathbf{P_{tot}}$ **Total power dissipation** — Maximum permissible value of I_F x U_F for given temperature.
  For small diodes this figure relates to the soldered condition with shortened leads.
  For power diodes a case reference temperature applies which is attained by suitable heat sinks.
  In a diode array the maximum permissible value is always listed for the sum of all component diodes.
- $\mathbf{P_{BR}}$ **Pulse power dissipation** — Maximum permissible pulse power dissipation in forward range for a given pulse time.
- $\mathbf{P_{in}}$ **Input power** — Maximum RF input power.
- $\mathbf{R_{thU}}$ **Thermal resistance, junction-ambient** — for still ambient air.
- $\mathbf{R_{thG}}$ **Thermal resistance, junction-case** — for infinitely good heat dissipation ($T_G = T_U$).
- $\mathbf{T_j}$ **Junction temperature** — Upper maximum permissible junction temperature.
- $\mathbf{T_U}$ **Ambient temperature** — Temperature of ambient still air.
- $\mathbf{T_{oper}}$ **Operating temperature** — Upper operating temperature range.

b) Characteristics

The stated characteristics are either mean values or upper (< = max.) or lower (> = min.) guarantee values within the data spread. Characteristics are properties of a component at specific operating points or with suitable measurement arrangement and apply at 25°C unless stated otherwise.In some cases, a number of the characteristics are listed for differing measurement conditions.

U_F **Forward voltage** — Voltage drop between anode and cathode for a given forward current (I_F).

U_Z **Zener voltage** — Typical working voltage of a Z-diode in the breakdown range for a given test current (I_Z).

U_{BR} **Breakdown voltage** — Value of reverse voltage producing a steep increase in the reverse current (breakdown) when slightly exceeded.

$\Delta U/\Delta T$ **Temperature coefficient** — Change of U_Z or U_F as a function of temperature; always signifies a positive temperature coefficient unless preceded by a minus sign.

C **Diode capacitance** — Total capacitance of a diode for a given test voltage (U_R) and test frequency (f).

C_1/C_2 **Capacitance ratio** — Available ratio of minimum and maximum achievable diode capacity at U_{R1} and U_{R2}.

f_g **Cut-off frequency** — Maximum operating frequency.

r_s **Series resistance** — Differential forward resistance for a given frequency.

r_z **Z resistance** — Differential (dynamic) resistance in Z breakdown region for a given test current. $r_z = \Delta U_Z/\Delta I_Z$.

r_r **Reverse resistance** — Differential reverse resistance.

Q **Q faktor** — Figure of merit for a resonant circuit at a given frequency.

$$Q = \frac{1}{2\pi \text{ x } f \text{ x } C \text{ x } r_s}$$

η **Rectification efficiency** — Demodulator rectification efficiency at a given frequency.

F **Noise figure** — for a given frequency.

L_s **Series inductance** — Equivalent inductance with short leads.

t_{rr} **Reverse recovery time** — Time from start of switching procedure of forward range (I_F) via the depletion phase and via the reverse range with elevated reverse current (I_R) until return of reverse current to a specified value (i_R) or U_R (see Fig. 15).

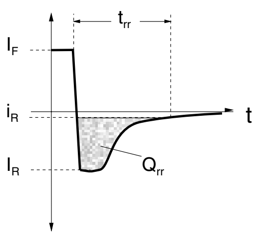


Fig. 15

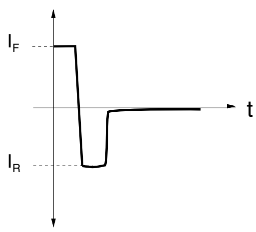


Fig. 16

Q_{rr} **Reverse recovery charge (storage charge)** — Total charge (cross-hatched area in Fig. 15) causing reverse delay (t_{rr}). This charge is measured in nanoampereseconds (nAs) = nanocoulomb (nC).

I_R **Reverse current** — Residual current in the reverse direction for a given reverse voltage and a temperature.

I_F **Forward current** — for a given forward voltage and temperature.

I_Z **Z current** — for a given Z voltage and temperature.

All symbols and definitions explained here are listed alphabetically in short form in the following, also including those not mentioned in the header of the table, i.e. merely used in special cases in the table text.

SYMBOLS AND DEFINITIONS (alphabetically arranged)

C	Diode capacitance
C_1/C_2	Capacitance ratio
F	Noise figure
f	Test frequency
f_g	Cut-off frequency
f_{res}	Resonant frequency
I_{AV}	Forward current (average)
I_{eff}	Forward current (rms)
I_F	Forward current (DC)
I_{FM}	Forward current (maximum peak)
I_{FRM}	Forward current (maximum repetitive peak)
I_{FSM}	Surge current (non-repetitive)
I_{op}	Operating current
I_p	Peak current
I_p/I_v	Peak/valley current ratio
I_R	Reverse current
I_v	Valley current
I_Z	Z current
I_{ZM}	Z current (peak value)
L_c	Conversion loss
L_s	Series inductance
N_r	Noise ratio
P_{BR}	Pulse power dissipation
P_{in}	RF input power
P_Q	RF output power
P_{tot}	Total power dissipation
Q	Figure of merit
Q_{rr}	Reverse recovery charge
R_{neg}	Negative resistance
R_{thG}	Thermal resistance, junction — case
R_{thK}	Thermal resistance, junction — ambient when mounted on printboard or substrate (SMD types) or heat sink
R_{thU}	Thermal resistance, junction — ambient
r_r	Differential reverse resistance
r_s	Differential series resistance
r_z	Z resistance
S_M	Magnetic sensivity
T_G	Case temperature
T_j	Junction temperature
T_K	Ambient temperature when mounted on printboard or substrate (SMD types) or heat sink
T_{oper}	Operating temperature
T_U	Ambient temperature
t_{rr}	Reverse delay time
U_{BR}	Breakdown voltage
U_{Cl}	Clamp voltage at I_{FSM}
U_{eff}	Input voltage (rms)
U_F	Forward voltage
U_{HF}	RF voltage
U_{op}	Operating voltage
U_p	Peak voltage
U_r	Equivalent noise ratio ($\mu V/\sqrt{Hz}$)
U_R	Reverse voltage
U_{RM}	Repetitive peak reverse voltage
U_v	Valley voltage
U_Z	Z operating voltage
Z_{ZF}	ZF impedance
ΔU_R	Voltage difference
$\Delta U/\Delta T$	Temperature coefficient
η	Rectification efficiency
τ	Carrier life, time constant

GB

EXPLANATIONS

I) General-Section 2, 5 and 6 (Data Tables)

1. "Type" column
All types are listed in alphabetical order. Outdated or insignificant types are set in small print. Type families are grouped together optically, i.e. not separated by a slash. In this case, the complete data is given only for the main type in the first line. For all other types, only the data differing from that of the main type is indicated together with the test conditions.

2. "Manufacturer" column
Names of manufacturers are abbreviated to save space. The complete names and addresses are listed alphabetically at the end of Section 1. We cannot assume responsibility for completeness and availability. When more than one manufacturer is named for any type, only the data is given relative to one manufacturer, since the data of any type differs slightly from one manufacturer to the other due to the differing test conditions.

3. "Fig./Pin-Code" column
All case identifications are listed in Section 7 with an alphanumerical Fig. number.
Similar case types are grouped together under a single letter and shown in roughly the same scale, thus facilitating comparison of size. The small letters following the slash identify the pin-code which is tabulated at the end of the drawings or on the yellow fold-out.
*A/B/C/D/E/F represent the case dimensions for drawings showing no dimensions.

4. "Application" (and remarks) column
The main application of each type is abbreviated to save space. This column also contains any remarks pertinent to, for instance, coding, further data on special types and other useful instructions. On subminiature types an alphanumerical type code is used (see also listed at end of Section 7).

Abbreviations in the "Application" column

asym	asymmetrical
C-Entlad	for discharge of capacitors
Di	Diode
Diac	3-layer trigger diode, symmetrical (see Explanations III)
F-Thy	Fast thyristor (see Explanations II)
GTO-Thy	Gate turn off thyristor (see Explanations II)
HA	TV horizontal deflection stages
Min	Miniature type
Opto-	Light activated thyristor
PUT	Programmable UJT (see Explanations IV)
SAS	Silicon asymmetrical switch (see Explanations III)
SBS	Silicon bilateral switch (see Explanations III)
SN	Switch-mode power supplies
SUS	Silicon unilateral switch (see Explanations III)
sym	symmetrical
Tetrode	P-+N-gate thyristor (see Explanations II)
Thy	Thyristor (SCR) (see Explanations II)
Thy-Br	Thyristor bridge configuration
Thy+Di	Thyristor+integrated antiparallel diode, reverse conducting (ITR) (see Explanations II)
Thy-Modul	Arrangement of numerous thyristors in a single case
Triac	Bidirectional thyristor (see Explanations II)
Trigger	4-layer trigger diode, asymmetrical (see Explanations III)
TV	TV applications
Typ-Code	Type code (see also list at end of Section 7)
UJT	Unijunction transistor (see Explanations IV)
VA	TV vertical deflection stages
ZV	Integrated trigger amplification
50Hz-Thy	Thyristor for mains operation (see Explanations II)
→	New type designation

II) Notes regarding Section 2 (thyristors)

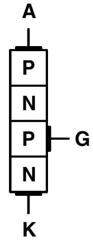
1. In general

Thyristors are silicon four-layer semiconductor elements with three junctions and a cathode-sided control gate (fig.1). They are mostly used as controlled rectifiers.

With an open gate connection, respectively without trigger pulse thyristors are blocked up in both directions and only a small off-state current flows (I_D or I_R).

Ignition requires a positive control voltage (U_{GT}) or control current (I_{GT}) at the gate opposite the cathode to decompose the carriers of the middle junction or an exceeding of the break-over voltage (U_{B0}) between anode and cathode the two main terminals, which may, however, result in destroying the thyristor (overhead ignition).

The once triggered thyristor remains conductive as long as current flows through both main terminals, which is larger than the respective type- related holding current (I_H), even if there is no trigger current at the gate any more. For conducting a short trigger pulse is sufficient.



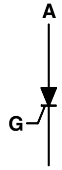


fig. 1

fig. 2

The thyristor is turned off when current applied falls below the holding current (I_H), so e.g. at the use of alternating current, as far as no trigger pulse is present every time at the zero-axis crossing of the positive half-wave (fig.2). In this case periodically every positive half-wave has to be triggered again. By timeshifting of the trigger pulse with regard to the start of each new half-wave the conduction angle and so the load current to be controlled can be changed continuously (fig.3+4).

Turning off small thyristors or special types (GTO's, Tetrodes) by negative trigger pulses is also possible.

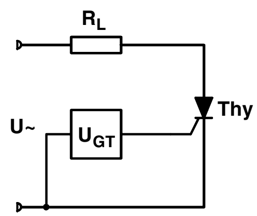


fig. 3

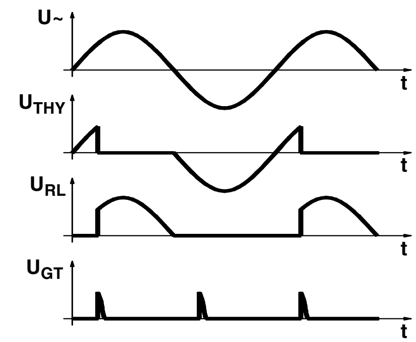


fig. 4

A certain minimum of driving power at the gate connection is necessary for normal triggering, which must be present until the thyristor has completely conducted (t_{gd}). This time-delay can be abbreviated through very steep impulses and/or overdriving. Exact information about the admissibility of such sort of operations can be received only in the trigger diagrams of the respective producer information.

Further information is broken down in the following section 2. "Data".

a) Gate turn off (GTO) thyristors

Unlike normal thyristors GTO's will turn off on receiving a negative gate pulse without requiring complicated turn-off circuits. However, they must not be subjected to a negative off-state voltage. In AC operation the latter must be blocked by a fast diode in the main current circuit.

b) Tetrodes

Thyristor tetrodes have contrary to thyristors and triacs besides a cathode-sided gate (G_K) an additional anode-sided gate terminal (G_A). This device is adequate to a circuit of PNP- and NPN-transistor like figure 8. The mostly fast switching ability of tetrodes makes (e.g. digital application) a shorter cycle time possible than with standard thyristors.

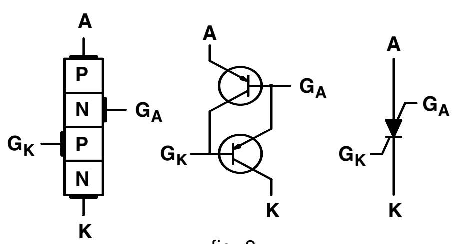


fig. 8

Triggering is effected by a positive control pulse applied to the cathode- gate (G_K) or a negative one to the anode-gate (G_A).
In addition a gate-controlled turning-off is possible by a negative control pulse applied to G_K or a positive one applied to G_A.

c) Thyristor + integrated anti-parallel diode (ITR)

The integrated diode makes these types reverse-conducting, i.e. exhibit no blocking behaviour on application of reverse voltages (diode characteristic). On application of positive voltages they behave like normal thyristors.

They mainly find application in TV horizontal deflection stages.

d) Triacs

"Triac" is the English short form for "three electrode alternating current semiconductor switch".
In the mode of operation the Triac behaves similarly to two antiparallel circuited thyristors, it is a bidirectional thyristor (triode) and so can be used as a full-wave rectifier for AC-voltage. The main terminals are called A_1 and A_2 (fig.5+6).

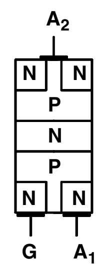


fig. 5

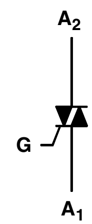


fig. 6

Ignition is possible either by positive or negative trigger pulses. As a result four triggering modes are possible, called quadrants (fig.7).

Q	A_2	A_1	G
1	+	-	+
2	-	+	+
3	-	+	-
4	+	-	-

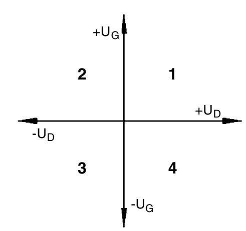


fig. 7

2. Data

All data named in the tables come from producer publications and have been carefully estimated and brought into a clear and comparable form. Inadequate information of a few, mainly foreign producers often didnot admit an exact and complete data information of their type ranges.

a) Limiting values

Limiting values listed in the table are absolute limiting dates, which may be exceeded in no case not even for a short period.

$U_{D/R}$ **Forward/reverse off-state voltage**
Maximum permissible forward or reverse DC-off state voltage.

$U_{DM/RM}$ **Forward/reverse repetitive peak voltage**
Maximum permissible positive or negative instantaneous value of the off-state voltage including all periodic peaks between the main terminals of the thyristor. Generally this value is valid up to the maximum operating temperature (T_{oper}).

For safety reasons by selecting the types a voltage distance of factor 1,5 has to be fixed. At mains with mostly unknown voltage overload this factor should be 2 to 2,5. If larger overload must be expected an excess overload protection must be installed.

U_B **Break over voltage**
Positive value of the off-state voltage at which the thyristor at a definitive trigger current is conducting (important for parallel operation).

U_{B0} **Break over voltage, gate open**
Positive value of the off-state voltage at which the thyristor is conducting without trigger current. This trigger operation may not be used in normal operation (danger of destruction).

I_{RMS} **RMS on state current**
Effective value (RMS) of the maximum permissible on-state current, which may not be exceeded even with optimum cooling (40 to 60 Hz mains operation).

I_{AV} **On-state current**
Maximum permissible arithmetical value of the sinusoidal on- state current at a known case temperature and/or a manufacturer suggested heat sink (half-wave circuit; 40 to 60 Hz mains operation; conduction angle 180°).

I_{TRM} **Limiting peak repetitive on-state current**
Maximum permissible peak value of the on-state current during a period. This value may not be exceeded even at the shortest conduction angle and best cooling.

I_{TSM} **Surge current**
Maximum permissible peak value of a 50 Hz sinusoidal half- wave. At operating with I_{TSM} junction temperature is exceeded and mostly the thyristor will lose blocking ability in forward direction. Therefore afterwards a recovery period is necessary (disconnection), i.e. this value may only be used in case of disturbances.

$\int i^2\,dt$ **i^2 t for fusing**
The maximum allowable value of the square of the instantaneous forward on-state current integrated over the time (T_{max}, t=10ms).

R_{thG} **Thermal resistance, junction to case**
Thermal resistance between junction and case. This value is the relation of the difference between maximum junction temperature and case temperature to maximum total power loss of the thyristors.

R_{thU} **Thermal resistance, junction to ambient**
Mainly used with low power devices and natural air cooling:

$$R_{thG} = \frac{T_j - T_G}{P_{tot}} \qquad R_{thU} = \frac{T_j - T_U}{P_{tot}}$$

T_{oper} **Operating temperature**
Upper maximum operating temperature.

T_j **Maximum junction temperature**
Upper maximum permissible junction temperature.

U_{GM} **Limiting peak gate voltage**
Maximum permissible gate control voltage (peak value).

I_{GM} **Limiting peak gate current**
Maximum permissible gate control current (peak value).

P_G **Gate power loss**
Arithmetical average of the gate power loss.

P_{GM} **Limiting peak gate power loss**
Limiting value of the peak gate power loss with possibly indicated maximum period.

U_T **On-state voltage**
Maximum on-state voltage (voltage drop) at defined instantaneous value of on-state current (i_T) between the main terminals.

b) Characteristics

Characteristics listed in the tables are according to the column heading the upper resp. lower maximum values of the spread of these parameters, if not otherwise specified by < or >.

$I_{D/R}$ **Off-state current**
I_D (forward off-state current) is mostly equal to I_R (reverse off-state current). This value is valid at defined voltage and temperature.

du/dt$_{krit}$ **Critical rate of rise of off-state voltage**
Maximum value of the rate of rise of voltage in forward direction, which, without a gating pulse and up to maximum operating temperature, does not switch the thyristor.
Capacitive currents in the crystal may at exceeding rates of rise lead to unintended ignition. This value is valid for mains operation and a voltage rise up to 67% of U_{DM}, if not otherwise specified.

di/dt$_{krit}$ **Critical rate of rise of on-state current**
Maximum rate of rise of current of a damped half-sine wave at operation up to maximum operating temperature, which may not be exceeded for reasons of thermical current spreading conditions inside the crystal without danger of destruction. This value is valid for mains operation and $U_R \leq$ 67% before triggering. The complete profit of di/dt presumes an ignition above the minimum value of I_{GT}.

Quadr. **quadrants**
Triggering mode is valid for I_{GT}, I_{GD}, U_{GT}, U_{GD}, only for triacs.

I_{GT} **Gate trigger current**
Maximum value of the spread of trigger current least necessary to trigger at defined T_j, U_D and general ohmic load. With smaller trigger currents than the listed ones a reliable triggering is not guaranteed. For some applications with higher di/dt (>10A/µs) a considerable larger trigger current is necessary (for information refer to ignition charts of the manufacturers). The trigger pulse has to remain (outlast t_{gd}) until the latching current (I_L) is reached, because otherwise the thyristor returns to the off-state.

Triggering during the off-state period, the off-state current (I_R) will rise considerably and cause additional loss, which have to be calculated too in total circuit design.

I_{GD} **Maximum gate-non-trigger current**
Maximum value of the spread of the highest trigger current, which does not cause triggering. This value is valid up to T_{oper} and 50% U_{DM}.

U_{GT} **Gate trigger voltage**
Maximum value of the spread of voltage drop between cathode and gate at applied I_{GT}. This value is valid at defined T_j, U_D and general ohmic load.

U_{GD} **Maximum gate-non-trigger voltage**
Maximum value of the spread of the highest trigger voltage, which does not cause triggering. This value is valid up to Toper and 50% U_{DM}.

I_H **Holding current**
Minimum value of on-state current at which the thyristor remains in the on-state condition.

I_L **Latching current**
Minimum value of on-state current at which the thyristor, after triggering, remains in the on-state.

t_{gd} **Gate controlled delay time**
Time from start of a steep gate pulse to a drop to 90% of the original value of the forward voltage U_D. Delay can be reduced by very steep and high gate pulses.

t_{on} **Turn-on time (=t_{gt})**
Time from start of a steep gate pulse to a drop to 10% of the original value of the forward voltage U_D (=gate controlled delay time + turn-on delay).

t_q **Circuit commutated turn-off time**
Minimum time required between zero crossover of the current from forward to reverse direction and the earliest return of a forward voltage.
Thyristor is returned forward as soon as it drops below the given t_q value thus setting an upper limit to the operation frequency.
At mains operation (40-60 Hz) the turn-off time can usually be ignored and thus an average for the spread range can be given, at best.
For fast thyristors, however, a guaranteed maximum is stated from which the maximum operation frequency can be established. The turn-off time relates to operation up to T_{max}.

t_{off} **Turn-off time**
Generally corresponds to t_q for thyristors.

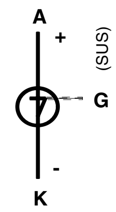
III) Notes regarding Section 5 (trigger diodes)

1.General

Trigger diodes are silicon three or four-layer semiconductor devices usually without a gate connection. For this reason the device will only gate when the break-over voltage of the type involved (U_B) is exceeded. Trigger diodes are suitable for pulse generation applications and thus for triggering thyristors, triacs, etc. due to their region of negative resistance.

a) Four-layer trigger diodes
Turn-on possible only in forward direction. Characteristic is asymmetrical (fig. 9).

b) Three-layer trigger diodes (diacs)
Turn-on possible in both directions. Characteristic is symmetrical (fig. 10).



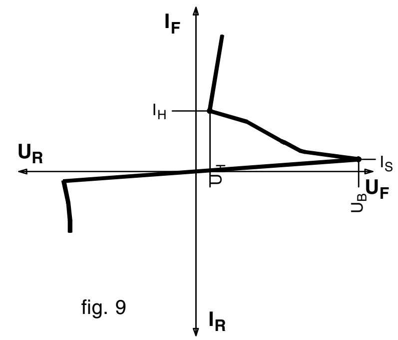
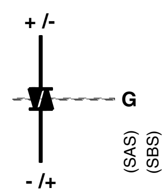


fig. 9

c) SUS (Silicon Unilateral Switch)
Same as four-layer trigger diode except with gate connection.

d) SBS (Silicon Bilateral Switch)
Same as three-layer trigger diode except with gate connection.

e) SAS (Silicon Asymmetrical Switch)
Same as three-layer trigger diode except with gate connection and asymmetrical characteristic.



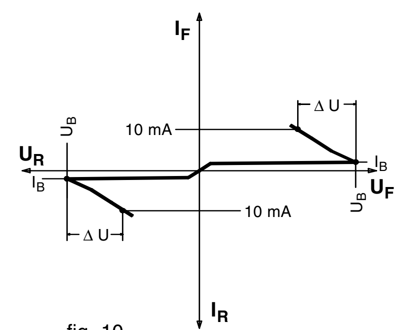


fig. 10

2. Data

U_B **Break over voltage (switching voltage)**
Mean value of the spread of voltage at which the trigger diode conducts.

I_B **Break over current (Diacs)**
Positive or negative off-state current at a voltage up to U_B.

Δ_U **Dynamic break-back voltage (Diacs)**
Voltage difference U_B - U_F at an on-state current of 10mA.

I_S **Switching current (four-layer diodes)**
Positive off-state current at a voltage up to U_B.

I_H/U_H **Holding current/holding voltage (four-layer diodes)**
Minimum value of the forward current or the forward voltage at which the diode remains conducted.

IV) Notes regarding Section 6 (Unijunction-transistors-UJT, PUT)

1. In general

a) Unijunction-transistors (UJT's)
UJT's are for the reason of their function more similarly related to thyristors and trigger diodes than to normal transis-tors. Therefore they are mentioned in this book.

They are silicon semiconductor devices consisting of an N-doped crystal with two facing base conne-ctions (B_1 and B_2) and a P-doped emitter diode diffused unsym-metrical in between (fig.11).

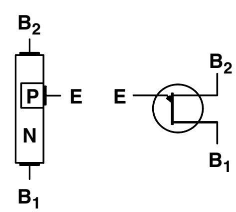


fig. 11

The equivalent circuit diagram (fig. 12) explains the mode of operation and fig.13 shows the principal curve.The latter shows a region of negative resistance, whereby UJT's for pulse gene-ration, oscillating circuits and triggering thyristors are specially qualified.

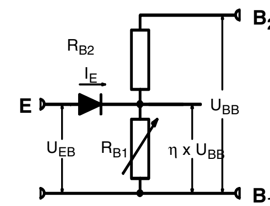


fig. 12

When applying a voltage (U_{BB}), the result at the emitter connection is, due to the interbase resistance (R_{BB}), a partial voltage corresponding to the applied voltage U_{BB} x η (intrinsic standoff ratio), provided that the emitter diode is open or biased in reverse direction.

fig. 13

b) Programmable UJT's (PUT's)

PUT's are again silicon four-layer semiconductor devices similar to thyristors. The name does not refer to the structure but to the mode of operation given by a PUT circuited with two external resistances. Contrary to the UJT the PUT offers variable adjustment of the intrinsic standoff ratio (η) (fig.14+15).

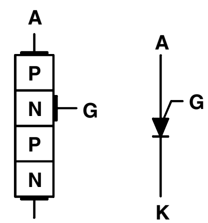


fig. 14

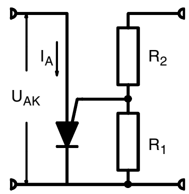


fig. 15

2. Data

a) Limiting values

U_{BB} Interbase voltage (UJT)
Voltage base 2 to base 1.

U_{EB} Emitter base voltage (UJT)
Voltage emitter to base 1.

U_{AK} Off-state voltage anode to cathode (PUT)
U_{GA} Off-state voltage gate to anode (PUT)
U_{GK} Off-state voltage gate to cathode (PUT)
i_{EM} Emitter current (UJT)
Maximum permissible emitter current (instantaneous value).

I_{FM} Anode current (PUT)
Maximum permissible anode peak current.

b) Characteristics

I_P Peak point current
Emitter current (UJT) or anode current (PUT) at listed peak point voltage.

I_V Valley point current
Emitter current (UJT) or anode current (PUT) at listed valley point voltage.

η Intrinsic standoff ratio
UJT: Ratio of the emitter to base 1 voltage (U_{EB}) to the interbase voltage (U_{BB}) at I_E=0.

$$\eta = \frac{R_{B1}}{R_{BB}}$$

PUT: Determined by the two external resistors R_1 and R_2 shown by fig.15.

$$\eta \approx \frac{R_1}{R_1 + R_2}$$

I_{EB0} Emitter cutoff current (UJT)
Emitter cutoff current at listed emitter to base 2 voltage, base 1 not connected.

I_{GA0} Gate cutoff current (PUT)
Gate cutoff current at listed gate to anode voltage (U_{GA}), cathode not connected.

I_{GK0} Gate cutoff current (PUT)
Gate cutoff current at listed gate to cathode voltage (U_{GK}), anode not connected.

R_{BB} Interbase resistance (UJT)
Inner resistance between base 2 and base 1 at listed interbase voltage (U_{BB}).

U_{EBsat} Emitter saturation voltage (UJT)
Emitter voltage in the region of saturation (on-state voltage) at listed emitter current (I_E).

U_F Forward current (PUT)
Anode to cathode voltage at listed forward current (I_F) in the region of saturation.

EXPLANATION OF SYMBOLS

di/dt_{krit}	critical rate of rise of on-state currentl
du/dt_{krit}	critical rate of rise of off-state voltage
I_{AV}	on-state current (mean value)
I_B	break-over current
$I_{D/R}$	forward/reverse off-state current
I_E	emitter current
I_{EB0}	emitter cutoff current
I_F	forward current
I_{GA0}	gate cutoff current, cathode not connected
I_{GaM}	anode-gate current
I_{GaT}	anode-gate trigger current
I_{GD}	max. gate-non-trigger current
I_{GK0}	gate cutoff current, anode not connected
I_{GkM}	cathode-gate current
I_{GkQ}	cathode-gate reset current
I_{GkT}	cathode-gate trigger current
I_{GM}	limiting peak gate current
I_{GT}	gate trigger current
I_H	holding current
I_L	latching current
I_P	peak point current
I_{RMS}	RMS on-state current
I_S	switching current
I_T	on-state current (instantaneous value)
I_{TRM}	limiting peak repetitive on-state current
I_{TSM}	surge current
I_V	valley point current
KK-Typ	type of heat sink
P_G	gate power loss
P_{GM}	limiting peak gate power loss
P_{GQ}	gate reset power loss
P_{tot}	total power dissipation
R_{BB}	interbase resistance
R_{thG}	thermal resistance, junction to case
R_{thU}	thermal resistance, junction to ambient
t	time
t_{gd}	gate controlled delay time
t_{gq}	reset time
t_{off}	turn-off time
t_{on}	turn-on time
t_q	circuit commutated turn-off time
t_r	rise time
T_G	case temperature
T_j	max. junction temperature
T_K	heat sink temperature
T_{oper}	max. operating temperature
T_U	ambient temperature
U_{AK}	off-state voltage, anode to cathode
U_B	break over voltage
U_{B0}	break over voltage, gate open
U_{BB}	interbase voltage
$U_{D/R}$	forward/reverse off-state voltage
$U_{DM/RM}$	forward/reverse repetitive peak voltage
U_{EB}	emitter base voltage
U_{EBsat}	emitter saturation voltage
U_F	forward voltage
U_{GA}	off-state voltage, gate to anode
U_{GaA}	off-state voltage, anode-gate to anode
U_{GaK}	off-state voltage, anode-gate to cathode
U_{GaQ}	anode-gate reset voltage
U_{GaT}	anode-gate trigger voltage
U_{GD}	max. gate-non-trigger voltage
U_{GK}	off-state voltage, gate to cathode
U_{GkK}	off-state voltage, cathode-gate to cathode
U_{GkQ}	cathode-gate reset voltage
U_{GkT}	cathode-gate trigger voltage
U_{GM}	limiting peak gate voltage
U_{GT}	gate trigger voltage
U_H	holding voltage
U_T	on-state voltage
Δ_U	dynamic break-back voltage
η	intrinsic standoff ratio
$\int i^2 dt$	i^2t for fusing